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HD 12098 and Other Results from Naini Tal - Cape Survey

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Abstract.

Naini Tal - Cape Survey is a survey started with the aim of searching for new rapidly oscillating Ap stars in the northern hemisphere and has discovered one mono-periodic roAp star HD 12098. The frequency separation of HD 12098 suggests a rotation period of 5.5 day for the star. The discovery of roAp oscillations in HD 12098 and the results of the multi-site observation campaign organized to resolve the ambiguity in the determination of the rotation period of HD 12098 is presented. The results of non oscillating Ap stars discovered in the survey and two promising roAp candidates HD 17431 and HD 207561 are also presented. If confirmed, the variability in HD 207561 will make it the first Am star showing roAP type rapid variability.

Key words: stars: roAp stars, stars-individual: HD12098,stars-individual: HD 207561, stars-individual: HD 17431, stars-individual: HD 25499, stars-individual: HD 38143, stars-individual: HD 38817

1. Introduction

Naini Tal - Cape Survey is a collaborative program between India and South Africa, initiated with the main aim of searching for new northern hemisphere rapidly oscillating Ap stars (roAp) and to study them (Seetha et al, 2001). RoAp stars are short period photometric variables discovered in 1978 by Kurtz (1978). The period of oscillations in these stars lie in the range of 5-21 minutes with typical amplitudes of few milli magnitude. The low amplitude of oscillations and the short periods demand a very stable site and atleast one meter class telescope for the study of roAp stars. For these reasons, the 104 cm Sampurnanand telescope at ARIES, Naini Tal is selected for the survey. For a summary of Naini Tal - Cape Survey, and the site characteristics and facilities available at ARIES, Naini Tal for variable star research, readers are referred to, Joshi (2005) and Sagar & Mary (2005).

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Naini Tal - Cape Survey is an ongoing program. Till 2004, we have searched for short period variability in a total of 63 stars and detected rapid oscillations in HD 12098 (Girish et al, 2001), δ Scuti oscillation in four stars (Joshi, 2005). The selection of the candidate stars for the survey is made mainly on the basis of their Ap nature, Strömgren colours, and temperature when ever available. On the basis of known roAp stars, Martinez et al. (1995) found that, roAp stars occupy specific Strömgren color space. To increase the chances of detecting new roAp stars, the candidates for the survey are selected mainly on these empirical limits on their Strömgren colours. Since the limits are only empirical, the selection criteria is relaxed so as to include those stars which might lie just outside these limits. In fact one of the six Strömgren colors ($\delta m1$) of HD 12098, the first roAp star discovered under the survey fall outside the corresponding limit.

The Ap stars which share similar properties as that of roAp stars, but do not show rapid variability are called as non-oscillating Ap (noAp) stars. The noAp stars hold equal importance as that of roAp stars for the understanding of roAp phenomenon. During Naini Tal - Cape Survey, we found that three stars HD 25499, HD 38143 and HD 38817 fall under the category of noAp stars. The amplitude of variability in these three stars, if any, is less than 0.2 mmag in the frequency range of 1-5mHz. In addition, we observed roAp variability in HD 17431 and HD 207561 on few nights, but the data at hand are not sufficient to confirm the variability in these stars. These results are discussed in the following sections.

2. HD 12098

HD 12098 is the first roAp star discovered in Naini Tal - Cape Survey. The star is a bright ($m_V = 7.9$) F0 star. The Strömgren color indices of the star ($b - y = 0.191,\ m_1 = 0.328,\ c_1 = 0.517$ and $\beta = 2.796$, Hauck & Mermilliod 1998) combined with the de-reddened parameters estimated using the calibrations by Crawford (1975) falls within the empirical limits suggested for roAp stars except for δm_1. The discovery of roAp oscillations in HD 12098, thus extends the limits on δm_1 suggested by Martinez et al. (1995) for probable roAp stars by a slight margin.

On the basis of Strömgren colors, HD 12098 was selected as a candidate for the survey and observed on the night of 1999 November 21. The discovery light curve plotted in Fig 1 clearly shows variability around 7.1 minutes.

The discovery and followup observations showed that the oscillation amplitude in HD 12098 vary from night to night, indicating plausible multi-mode oscillation and/or rotational modulation. To determine the nature of oscillations, HD 12098 was observed on six nights from Gurushikhar observatory, Mt. Abu and ARIES, NainiTal for a total of 65 hours.

The analysis of individual nights' data confirm the modulation in the amplitude of oscillation. The amplitude modulation in roAp stars is caused mainly by two

processes. First by beating of close spaced periods and second due to the rotation of the star (Kurtz, 1982). To identify the nature of oscillations in HD 12098, the data obtained from Mt.Abu was combined on a common time scale and subjected to discrete Fourier transform (DFT) (Deeming, 1975). The significance level of the periods in the amplitude spectrum was determined on the basis of local noise. The running average of amplitudes of group of fifty frequencies are computed as the local noise while treating all the peaks in the data are due to noise. The significance level was set at four times the local noise level (see, Breger et al, 1996). Any peak lying above this limit was treated as real. In Figure 2 this significance limit is shown in the dotted line. The oscillation around 7.1 minute (2.173 mHz) well above the significance limit is clearly seen in the Figure.

In Figure 2, an unresolved frequency very close to the alias peak (marked ν_2) was clearly seen. To recover this frequency and to check for any other peaks that might be buried under the main frequency at ν_1, a noise free sinusoid with the amplitude and frequency corresponding to ν_1 was subtracted from the time series (prewhitening). The residual data was subjected to DFT again. The resulting amplitude spectra is plotted in the second panel of Fig.2. The spectrum show two peaks at 2.1641 & 2.1759 mHz with similar amplitude. The frequency difference between the two frequencies suggested one of them to be the alias of the second frequency. Typically the real frequency will have a higher amplitude and the aliases will be of lower amplitude. But, for amplitudes close to the noise level, this may not be true, making it difficult to differentiate the real peak from the alias.

Girish et al (2001) interpreted the second frequency as the rotationally split component of the main frequency and predict a rotation period of either 1.22 or 5.5 day for HD 12098. The ambiguity was due to the ambiguity in the identification of the second frequency. The magnetic field measurements of HD 12098, however favour the longer rotation period (Wade et al., 2001).

Multi-site campaign

The single site observations of HD 12098 showed the second frequency as the rotationally split component of the oscillation frequency of HD 12098. However, the second frequency suffered from 1 cycle/day alias ambiguity.

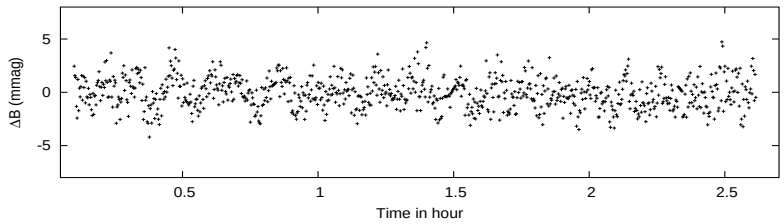

Figure 1. Discovery lightcurve of HD 12098 observed on 1999 November 21.

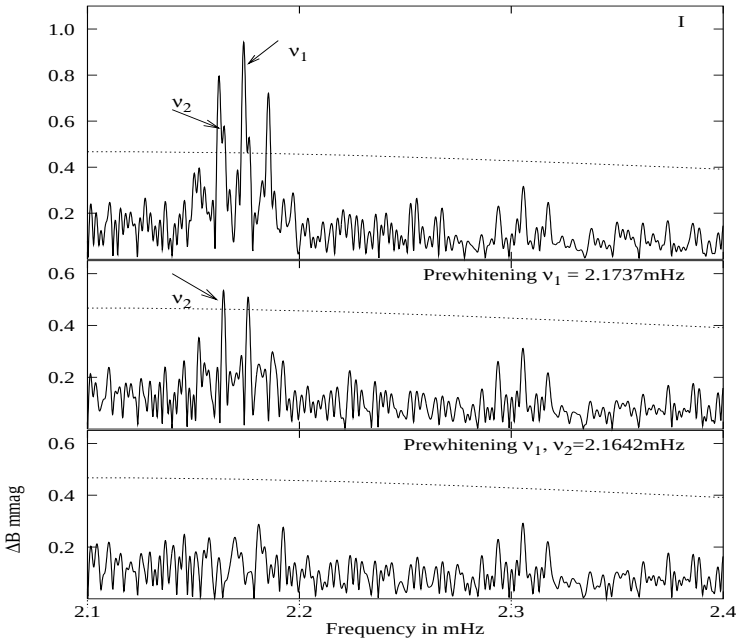

Figure 2. Amplitude spectra of the data obtained from Mt.Abu merged together. See text for details

With the main aim of resolving the ambiguity in identifying the second frequency, and hence, rotation period of the star, a multi-site observation campaign on HD 12098 was organized in October/November 2002. The campaign involved a total of eleven observatories, with ten observatories finally contributing to the data. A total of 394 hours of useful data extending over 28 nights with 45% duty cycle were obtained.

From the analysis of the multi-site data, mainly five frequencies separated by $\delta\nu = 2.14 \pm 0.02$ mHz were obtained. The plausibility of such small difference arising due to independently excited modes was already ruled out (Girish et al, 2001). Assuming the frequency separation to be due to rotational splitting, the equal separation of the frequencies gives a rotation period of $\Omega = 5.41 \pm 0.05$ days for HD 12098, very close to the 5.5 days rotation period predicted by Girish et al (2001) assuming 2.1759 mHz as the real frequency instead of $2.1641mHz$. The amplitude modulation of oscillations of individual nights' data also favours a period close to 5.41 days. Detailed observation and analysis results of the multi-site campaign will be published elsewhere (Seetha, S., Girish, V., et al, 2005).

3. Non oscillating Ap stars

Non oscillating Ap stars hold equal importance in the understanding of roAp phenomena. The systematic difference between the noAp stars and roAp stars can help us in the understanding of possible reasons for the incidence of oscillations in roAp stars. During Naini Tal - Cape Survey survey, three Ap stars were found to fit in to noAp star category. The three noAp stars HD 25499, HD 38143 and HD 38817 are discussed briefly.

3.1 *HD 25499*

HD 25499 satisfies all the six Strömgren colors used for identifying probable roAp stars. The star was observed on six occasions for a total of nine hours and found to show no variability at an amplitude limit of 0.2 mmag in the frequency range $1 - 5$ mHz. The amplitude of oscillation, if any would be below 0.2 mmag at 3σ confidence level. The lightcurve and the amplitude spectrum of HD 25499 observed on 10 Nov 2003 is plotted in Figure 3 and Figure 4 respectively. Though, there seems to be a peak above the significance level around 0.6 mHz corresponding to 28 minutes, it is not considered real due to the absence of similar period in the other observations.

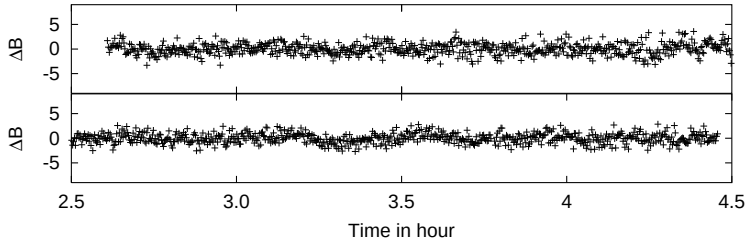

Figure 3. Lightcurve of HD 25499 observed on the night of 2003 November 10.

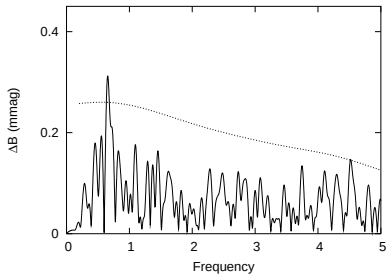

Figure 4. Fourier transform of the light curve plotted in Figure 3. The dashed curve represents significance limit at three times local noise level.

3.2 *HD 38143*

HD 38143 is an A2 star whose Strömgren color indices lie well within the empirical limits suggested by Martinez et al. (1995). The star was first observed on 23 January 2000, on three nights in 2002 and two nights in 2003 for a total of 22 hours. No variability was seen in all the runs at an amplitude limit of $0.3-0.4$ mmag. The lightcurve of HD 38143 observed on 2003 November 19 is plotted in Figure 5 with the corresponding amplitude spectrum in Figure 6. The available observations on HD 38143 suggest that the star is a noAp star, unless, HD 38143 has a very long rotation period or the oscillations if any have amplitudes below our detection limit ($< 0.3mmag$).

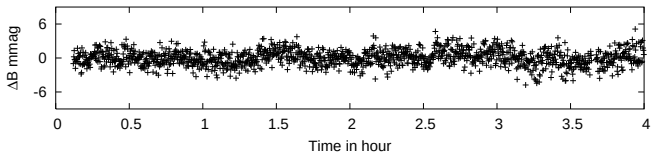

Figure 5. Lightcurve of HD 38143 observed on 2003November 19.

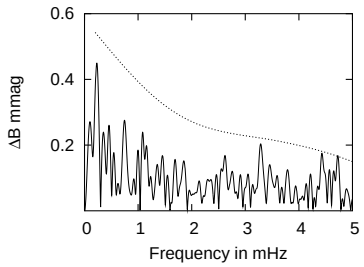

Figure 6. Amplitude spectra of lightcurve plotted in Figure 5

3.3 *HD 38817*

HD 38817 is classified as an A2 star. Only three of the six Strömgren colors (H_β, m_1, dm_1) satisfy the limits suggested for a probable roAp star, while c_1 lies with in 10% of the corresponding limits. The star was selected as a candidate star for Naini Tal - Cape Survey to check the possible extension of these limits, but turned out to be a non-variable at a limiting amplitude of 0.2 mmag. The star was observed for a total of 14 hours over four nights with the last three nights' observations extending for more than three hours each. The lightcurve and the corresponding amplitude spectrum of HD 38817 observed on 2003 November 09 are plotted in Figure 7 & 8 respectively. From the analysis of the data we conclude that HD 38817 is a noAp star at a limiting amplitude of 0.4 mmag at 3σ confidence level.

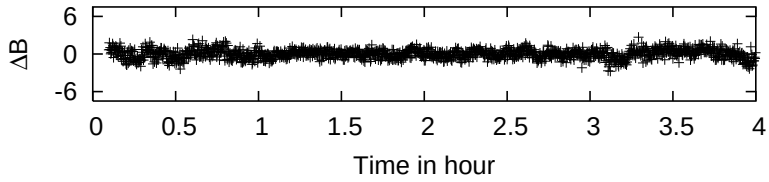

Figure 7. Lightcurve of HD 38817 observed on the night of 09 Nov 2003.

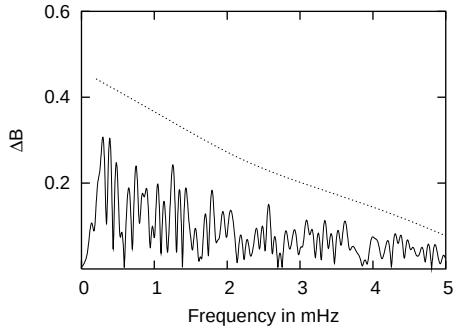

Figure 8. Plot of amplitude spectrum of the lightcurve plotted in Fig.7

4. Probable roAp star candidates

In the course of our survey, we observed variability in the frequency range of 1-5 mHz in two stars HD 207561 and HD 17431. But, the data on hand are not sufficient to confirm variability in these stars. HD 207561 is classified as an Am star (Floquet, 1975) and the confirmation of rapid variability will make it the first Am star showing roAp type variability. For the benefit of the others who may be interested in these stars, we briefly describe them.

4.1 *HD 207561*

HD 207561 is an F0 III star whose Strömgren colours fall well within the empirical limits for probable roAp stars. The star was observed on 2000 December 16 for the first time. The lightcurve and the corresponding Fourier spectrum of HD 207561 obtained on two consecutive nights 2002 December 6 & 7 are plotted in Figure 9 clearly show regular variations. Similar variations were absent in the comparison star data observed simultaneously with the second channel.

Both the lightcurve and the amplitude spectrum of HD 207561 plotted in Fig.9 clearly show regular variability around six minutes on two different nights. The absence of similar variation in the comparison star rules out the possibility of local effects. But the absence of six minute period in the followup observations do not

allow us to confirm rapid oscillations in the star. Also the period is very close to six minutes. When ever periodicity of integral multiple of a minute is detected, care should be taken to rule out the plausibility of drive error or other instrumental effects mimicking regular variability. Another likely reason for the non-detection of oscillations in the follow up nights might be due to mis-identification of the star. However, the confirmation of the presence or absence of oscillations in HD 207561 will be important as it will make HD 207561 the first Am star with roAp type variability.

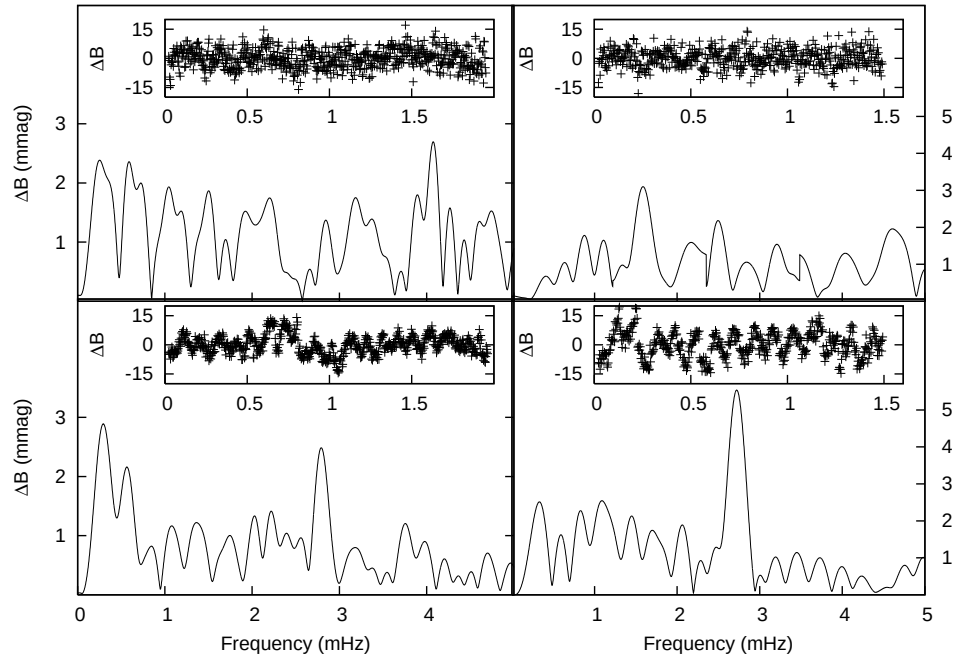

Figure 9. Lightcurves and amplitude spectrum of HD 207561 observed on the nights of 6th Dec 2000 (left panels) and 07 Dec 2000 (right panels). The top two panels shows the plots of the comparison stars while the bottom panels corresponds to HD 207561. A peak around 6.1 minute period is clearly seen in both amplitude spectrum and lightcurve of HD 207561 which is absent in the comparison star data.

4.2 *HD 17431*

HD 17431 is classified as an A3 star. The Strömgren color indices of the star satisfy all the six Strömgren parameters suggested for a probable roAp star. The star was first observed on the night of 2000 October 2000 09. The Fourier transform of the data showed a peak around 8.8 minutes. Similar periods were observed in the

follow up observations though not with very good signal except, on 2000 October 10. In Figure 10, the amplitude spectrum of the data obtained on 2000 October 10 and 2001 December 6 are plotted, which indicate the presence of a period around 8.8 minutes. Though, similar variability near this period was seen on other nights, the nights were not photometric and hence, prevents from confirming variability in HD 17431.

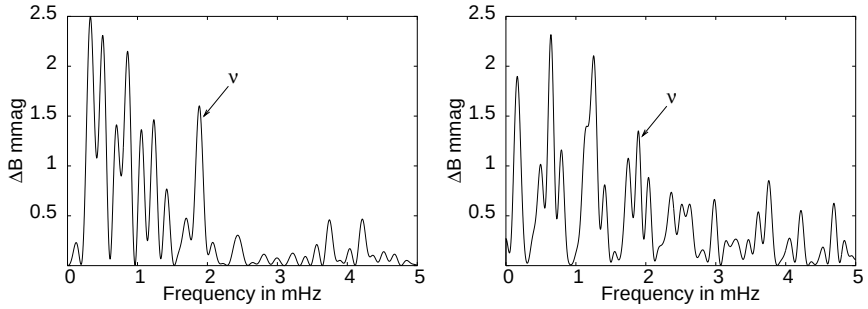

Figure 10. Amplitude spectrum of HD 17431 observed on 10th October 2000 and 6th December 2001. The peaks marked as ν corresponds to ~ 8.8 minutes.

5. Conclusions

We present a brief summary of the main results of Naini Tal - Cape Survey conducted from late 1999 to early 2004. During this period one roAp star HD 12098 a mono periodic oscillator was discovered. The amplitude modulation of the pulsation frequency and frequency splitting observed in HD 12098 suggest a rotation period of ~ 5.4 days for the star. The survey also resulted in the classification of three stars HD 25499, HD 38143 and HD 38817 as non oscillating Ap stars, useful in the understanding of the differences between roAp and Ap stars sharing similar properties of roAp stars but no oscillations. Also presented were two promising roAp candidates HD 17431 and HD 207561 which showed variability in few observations. Further observations on the two are needed to confirm variability in these stars. The confirmation of oscillations in HD 207561 will be an exciting result as it will make HD 207561 the first Am star to show rapid variability.

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